IDENTIFYING SYSTEM PATTERNS TO RESOLVE CHALLENGES IN THE TEST AND EVALUATION OPERATION

THESIS

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Abstract

This research focuses on identification and description of patterns used in Test and Evaluation (T&E) operations. Patterns are defined as named and well-known problem/solution pairs that can be applied in new contexts, with advice on how to apply it in a novel situations and discussion of its trade-offs, implementations, and variations. They have been well established and used in software engineering, but have only recently been considered for systems engineering. In the Department of Defense (DOD), T&E is required for all acquisitions prior to transitioning into operations. As identified and described in this thesis, each of the patterns fits in one of the three categories: behavioral, creational, and functional. The research has identified eight named patterns to include: primary pattern, objective pattern, cost estimating pattern, scheduling pattern, risk management pattern, work acceptance process pattern, hazard control pattern, and test team pattern. The implementation of patterns by Department of Defense is expected to alleviate some of the common challenges encountered during T&E, provide a consistent higher quality and expectation, as well as efficiently use test infrastructure and personnel resources.

To My Family

Acknowledgments

I would like to express my sincere appreciation to my research advisor, Dr. John Colombi for his guidance and support throughout the course of this thesis effort. The insight and experience was certainly appreciated. Most importantly, I greatly appreciate the days he was available to review my thesis paper even during his personal time; on leave, on temporary assignment duty away from home station, and/or during after-hours.

Daniel Mutunga

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I. INTRODUCTION

General Issue

This research work concentrates on identifying and describing some of the patterns and challenges found in Test and Evaluation (T&E) operations. As described in (Larman, 2004), patterns are named and well-known problem/solution pairs that can be applied in new contexts, with advice on how to apply it in a novel situations and discussion of its trade-offs, implementations, and variations. Implementation of patterns in T&E operations by Department of Defense T&E communities is expected to alleviate or eliminate some of the common challenges encountered during the T&E operations.

Research Objectives/Questions

Patterns have been in use in software development community for a while. Contrary, the use of patterns in T&E processes has not been common. The objective of this thesis is to identify and describe the T&E patterns that can be used to alleviate or eliminate some of the challenges encountered during T&E operations. To accomplish thesis objective, the following research questions in Table 1 will be investigated.

Table 1. Research Objectives and Questions

Objective	Research Question
Identify challenges encountered during T&E Operation	How to identify some of the challenges encountered by a typical T&E organization?
Determine and discuss the patterns utilized in T&E Operation	How to determine the some of the T&E patterns that organizations can use to plan,

	execute, and report before, during, and after T&E event?
Describe the use of patterns to resolve challenges encountered during T&E Operation	How could the T&E communities use the patterns to overcome challenges encountered during T&E operations?

Methodology

Through observation and review of project documentation, patterns in T&E operations can be identified. This thesis uses the observation and review methodology to determine the patterns that are common in T&E operations and have never been identified and implemented as patterns. Additionally, through observation and review, some of challenges encountered during T&E operations are identified and described. Finally, an association of challenges to patterns will be conducted showing how the patterns could help alleviate or eliminate the impact of the associated challenges.

Assumptions

The following assumptions are used in this thesis.

(1) T&E patterns are inherently used in T&E environment, like patterns of design are used in engineering

(2) The T&E patterns should address problems/challenges and be applicable to all the projects and systems under test

(3) There are cost, quality, and schedule benefits for using T&E patterns

(4) Patterns can be identified and described

(5) Only patterns for DOD T&E Operation are considered

(6) Investigation of T&E patterns for systems and processes are for unclassified information only

Implications

T&E patterns are applied across the DOD T&E organizations to avoid costly processes, reduce schedule risks, and achieve better results. Since there are numerous T&E projects in the DOD supporting different systems, T&E organizations have adopted patterns that suit their T&E requirements.

II. LITERATURE REVIEW

Chapter Overview

This chapter presents the literature review on the previous work on the same topic or similar research conducted. As described in (Creswell, 2002), literature review accomplishes several purposes. In this thesis the literature applicable to T&E Operation in the DOD and System and software patterns will be covered.

Test and Evaluation

T&E is the process by which a system or components are compared against requirements and specifications through testing. The results are evaluated to assess progress of design, performance, and supportability (Claxton, 2005). According to (USD(AT&L), 2007) the test and evaluation shall be integrated throughout the defense acquisition process. Structured test and evaluation provides essential information to decision-makers, assess attainment of technical performance parameters, and determines whether systems are operationally effective, suitable, survivable, and safe for intended use. This directive mandates the conduct of test and evaluation, integrated with modeling and simulation, to facilitate learning, assess technology maturity and interoperability, facilitate integration into fielded forces, and confirm performance against documented capability needs and adversary capabilities. As described in (USD(AT&L), 2008), the fundamental purpose of T&E is to provide knowledge to assist in managing the risks involved in developing, producing, operating, and sustaining systems and capabilities. T&E measures progress in both system and capability development. T&E provides knowledge of system capabilities and limitations to the acquisition community for use in improving the system performance, and

the user community for optimizing system use in operations. T&E expertise must be brought to bear at the beginning of the system life cycle to provide earlier learning about the strengths and weaknesses of the system under development. The goal is early identification of technical, operational, and system deficiencies, so that appropriate and timely corrective actions can be developed prior to fielding the system. The DOD employs three formal types of T&E in the acquisition of weapon systems: Developmental Test and Evaluation (DT&E), Operational Test and Evaluation, and Life-Fire Test and Evaluation (LFT&E) (Defense Acquisition Guide, 2012). The DT&E is the disciplined process of generating experimental performance data from systems, subsystems, components and materiel for the purpose of informing optimum solutions and the state of performance progress toward design performance goals. The OT&E determines the operational effectiveness and operational suitability of a system under realistic operational conditions, including joint combat operations; determines the satisfaction of thresholds in the approved JCIDS documents and critical operational issues; assesses impacts to combat operations; and provides additional information on the system's operational capabilities. The LFT&E objectives provide a timely assessment of the vulnerability/lethality of a system as it progresses through its design and development, prior to full-rate production. The Test and Evaluation (T&E) process is an integral part of the Systems Engineering Process (SEP), which identifies levels of performance and assists the developer in correcting deficiencies (Defense Acquisition University, 2005).

In (Fabrycky, 2006) the general T&E process as taught in Systems Engineering Schools such as Air Force Institute of Technology (AFIT) is presented. Two steps were discussed during the course. Firstly, the preparation for system T&E is conducted. This

step commences after the initial planning, and prior to the start of formal evaluation. The preparation includes selection of test item(s), establishment of test procedures, selection of test site, selection and training of test personnel, preparation of test facilities and resources, the acquisition of support equipment, and test supply support. Second step is conducting system test, data collection, and test reporting. During this step, the system is tested per test plan and data collected and analyzed which leads to an assessment of system performance and effectiveness characteristics.

Challenges Encountered During T&E Operations

The following are some of the challenges experienced by the author and personnel in T&E community. The identification of the challenges was by review of past T&E documentation and informal input from personnel in the T&E community. These challenges, treated as risks, can have serious impact on project schedule, cost, and system quality. Patterns are developed to alleviate the impact of or eliminate the challenges.

Cost Overruns

Cost overruns usually occur due to limited budget, scope creep, and poor project management. Due to requirements to conduct T&E processes for all DOD systems, limited funds are distributed for each item resulting in risk of scheduling to do too much with too little. In these situations there are always risks for cost overruns. Usually the funds budgeted for the T&E process are exhausted before the project is completed. If the sponsor cannot provide more funds to complete the project then the T&E organization either uses the funds for operating costs to complete the project or just terminates the project. Termination of a project could result in a bad reputation to the testing

organization resulting in the loss of future project opportunities. Additionally, using funds budgeted for other projects or project tasks for T&E purposes can impact the outcome of other projects or the health of organization. The cost challenges can be alleviated by proper project management that includes better budgeting of funds and prioritizing of events conducted. A Cost Estimating process that accounts for all project costs is used to reduce the risk of insufficient funds to a project. The major cost elements in the cost estimate are labor hours, travel, and equipment/material procurement costs.

Safety Hazards

T&E operation safety hazards pose the danger of personnel injury and/or equipment damage when the mishaps occur. Some of the common safety hazards during T&E operation include accidental ammunition initiation during inspection, laser injury during laser operations, cuts and bruises during equipment setup, and chemical burn or poisoning during explosive lab testing. Prior to commencement of a T&E operation, all potential hazards are identified and mitigation procedures implemented to reduce the probability of the mishap happening and its effect if it happens. Table 2 is a sample hazard analysis table found in (CRANE, 2009) that shows recommended steps to reduce the probability and impacts of mishaps. Mishaps are likely to result to death or serious injury to personnel or damage to test equipment. A serious mishap resulting in death or serious injury to personnel could have serious damage to an organization from bad reputation to shutting down.

Table 2. Hazard Analysis

Procedure:	Branch:	Revision Number:

Process Step	Hazard	Mishap Triggering Event	Potential Mishap	Prelim Risk Index	Hazard Mitigation Requirements	Final Risk Index

Strict Schedule

Time constraint in the DOD and the need to rapidly provide systems to the users pose schedule challenge to the T&E community. Timely analysis and reporting of operational and live fire test results are critical to the DOT&E mission, as well as the mission of every test agency. It is essential that our organizations analyze test data and formally report on test and evaluation as soon as practicable, regardless of whether a formal report is required by regulation or statute. Test results are most effective when they provide feedback as early as possible within the acquisition process. Delays in reporting can prevent senior leaders from recognizing serious problems that may unnecessarily risk the lives of our Service members (Gilmore, 2010). Usually the developer provides the expected Period of Performance (PoP) in their Work Orders or Statement of Work indicating when the work agreed upon is expected to be completed. Given the strict PoP, the T&E agency determines the schedule that will meet the PoP requirement. With multiple concurrent projects in an organization with similar resource requirements, the challenge is to appropriately schedule the right personnel, equipment, and facilities for the project to ensure timely completion of project.

Unskilled and Insufficient Workforce

DOD consists of diverse workforce possessing different skills sets and experience levels. For instance, there are military veterans in the T&E community with tremendous amount of experience on military systems gained during their time in service and skilled

personnel with advanced college degrees. The combination of experience and skills produces a strong workforce to support the T&E efforts in the DOD. However, a lot of times both virtues, skill and experience, are required to accomplish most T&E tasks. Lack of the personnel possessing both virtues is a challenge since it requires an organization to hire two people to perform work that can be completed by one person. In other cases, there might be too much of one virtue and too little of the other. In this situation, there will not be sufficient personnel to support project tasks and the organizations are at risk of failing to meet sponsor schedule requirements. The other challenges are trying to integrate the DOD's diverse community into a single unit to achieve the T&E objectives.

Unavailability of Test Equipment

Test equipment includes the equipment set up for data collection purposes and support equipment. The data collection equipment includes but is not limited to radar systems, high speed video equipment, computers, and cameras. The support equipment includes but is not limited to vehicles, weather stations, conditioning chambers, portable toilets, generators, and trailers. The challenges experienced with test equipment are unavailability of the appropriate equipment due to lack of funds to buy the equipment, damage during testing, or the equipment being used in another operation. In the situation where the equipment is unavailable to support the test, there are always risks for schedule delays, late delivery of customer products, loss of personnel to other projects, and cost overrun due to downtime. The equipment risks can be reduced by ensuring that the equipment is available and ready for test and is being operated by trained personnel during testing.

Strict DOD Policies

The policies in place ensure that the DOD T&E efforts are conducted safely without risks to the environment, testers, and general population. The policies in explosive testing environment require agencies to utilize designated test ranges and air space, control the explosive residue, and perform thorough cleanup and dispose of the waste in designated hazardous waste disposal areas. Failure to adhere to the policies could lead to the shutting down of the organization. Locally, the SOP for each project contains the summary of the policy requirements that need to be met. The SECNAVINST 5000.2E navy instruction (2011) provides guidance on policies for acquisition of all Department of Navy systems.

Inclement Weather

DOD organizations conduct T&E operations throughout the year under all weather conditions. The T&E projects are scheduled based on the requirements of the project and availability of test resources including personnel, facilities, funds, and time. A project with environmental condition testing requirements such as temperature, wind, dust, and humidity are scheduled to be tested at the sites with the appropriate weather conditions. For instance, test requiring cold temps would likely be tested in winter times or in cold areas like Alaska. Likewise, a project with humidity requirements would likely be conducted in high humidity areas or during wet seasons. Weather challenges are encountered when there are storms during testing, temperatures too high or too cold posing health hazards to the test team. Sometimes storms are accompanied by lightning. Inclement weather usually results to shutting down the operations risking schedule

delays, cost overruns, and loss of key personnel and facilities/equipment to other scheduled tests.

Difficulty in Data Collection

T&E is the process of exercising the system in accordance with the test plan to ensure that data is collected to support the evaluation plan. Test execution includes executing a pilot and record test, conducting data reduction, validation, and analysis, and conducting a data review to ensure data is adequate to support evaluation. Collection of invalid data results in incorrect evaluation of the system. Difficulty in collecting correct data could be as a result of having wrong data collection equipment, unskilled data collectors, poorly defined data collection requirements, and using faulty equipment.

Lack of Collaboration

There are many stakeholders involved in a T&E project. The major categories of the stakeholders are the testing organization, system developing organization, and program office. The testing organization consists of the project engineers, data collectors, data analysts, equipment operators, range support personnel, safety personnel, and subject matter experts. The system developing organization may include the contractor designing and manufacturing the system. The program office consists of the program manager leading the effort of acquiring the system and ensuring successful transition to the warfighter. The T&E organization works with all the other stakeholders during the development of the system to transition to the user. Effective collaboration with all the stakeholders is of paramount importance to ensure successful completion of the T&E process. Challenges occur when the stakeholders are not willing or able to work together.

It is stated in (Gilmore, FY 2012 Annual Report, 2012) that the lack of critically needed collaboration among the technical, test, and requirements communities is not new. The 1986 Packard Commission found that success in new programs depends on “an informed trade-off between user requirements, on one hand, and schedule and cost, on the other”. The participants could be remotely located from each other and reluctant to travel or participate in teleconferences. Some stakeholders may not be willing to accept necessary changes to ensure execution of the T&E process resulting in delayed or cancelled projects.

Unavailability of Test Facilities

Test facilities include the test ranges, bases, and laboratories used for various T&E Operations. In February 2012, I identified shortfalls in electronic warfare test resources that prevent adequate developmental and operational testing of many systems, including, but not limited to, the Joint Strike Fighter (Gilmore, FY 2012 Annual Report, 2012).

Due to the hazardous nature of most DOD test operations, only approved sites by the government are designated for testing conducting DOD operations for T&E efforts. These sites are remotely located inside the Continental United States (CONUS) and outside Continental United States (OCONUS). Many of the test facilities are also used by active military for operations and exercise. T&E organizations usually have access to these sites but only when they are not required for military training exercises. Any schedule conflict with military exercise and T&E operations results in cancellation of the T&E operations or postponement leading to delayed evaluation of the system.

Additionally, too many T&E events happening at the same time results in schedule delay or requirement to travel to sites located far away from the personnel supporting the test. Usually these challenges results in increased costs and schedule delays. Figure 1 in shows the ranges designated for DOT T&E operations.

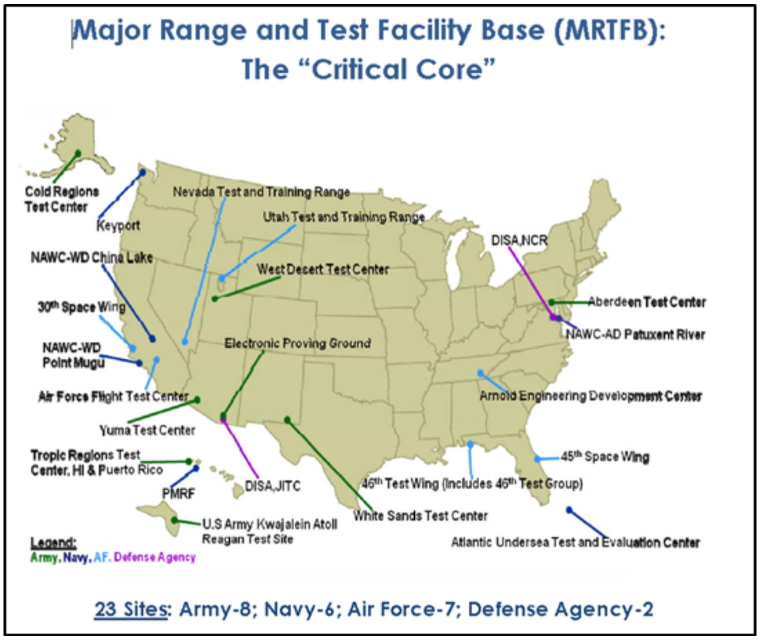

Figure 1. Test Ranges

Poor Project Management

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements (Project Management Institute, 2008). Usually the personnel leading T&E projects are usually engineers possessing limited or no project management skills. Without necessary tools of project management, it becomes quite challenging to successfully complete major T&E projects. Some of the issues associated with poor management include poor documentation, poor scheduling of events, poor distribution of roles to personnel, and poor management of funds. The patterns developed in this research work would help alleviate project challenges faced by

T&E communities. Figure 1 in (Defense Acquisition University, 2005) shows test-related documentation that the program manager is responsible for.

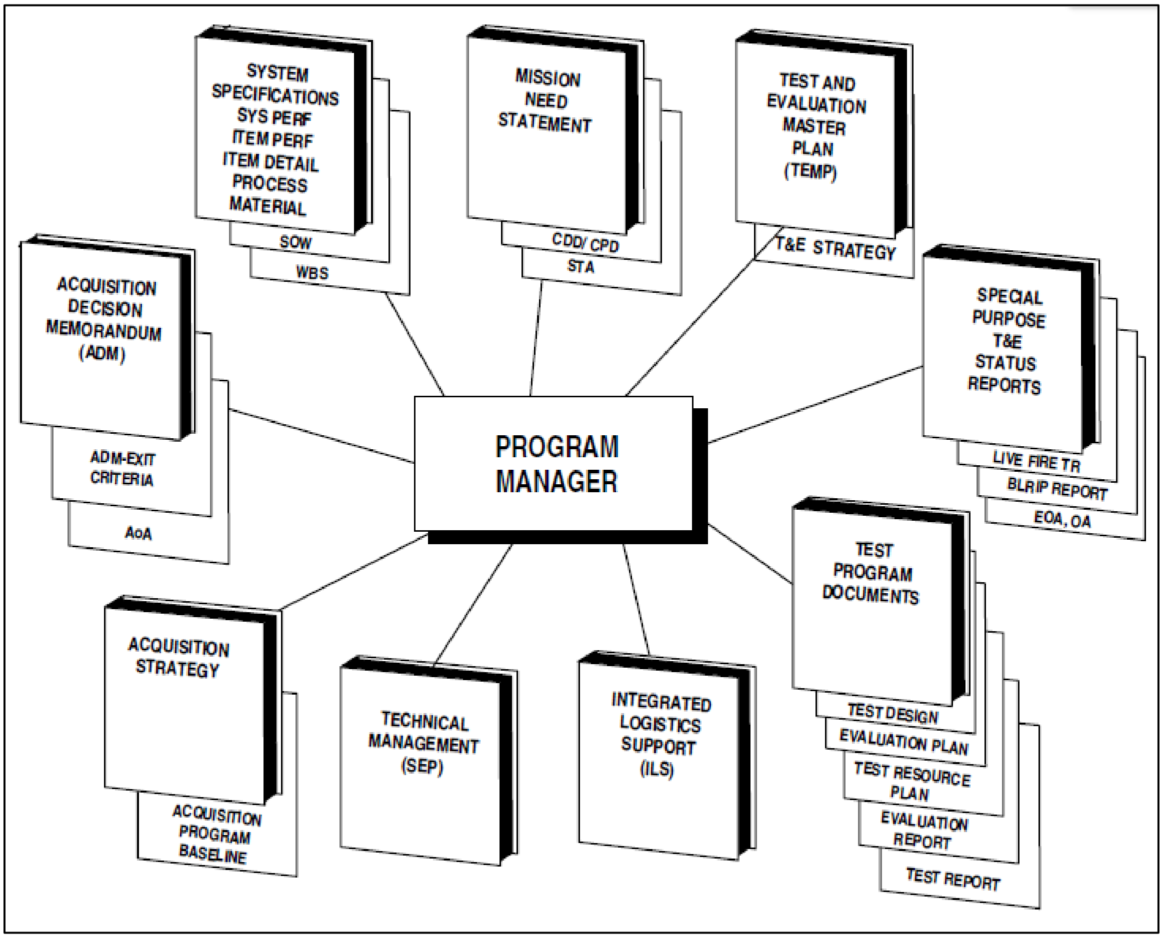

Figure 2. Test Related Documentation

T&E is one of the major requirements in Defense Acquisition Management System. Successful T&E provides data to the decision makers for analysis to determine if the DOD system is ready to transition to the warfighters. Failure to manage the projects correctly could lead to invalid evaluation leading to delays or cancellation of programs. The size and complexity of the DOD and pressure to rapidly transition systems to the warfighters contribute to challenges facing the T&E organizations during T&E execution.

The consequences of poor program management include cost overruns, schedule delays, and delivery of poor quality products.

System and Software Design Patterns

In software engineering, a design pattern is a general reusable solution to a commonly occurring problem within a given context in software design. It is a description or template for how to solve a problem that can be used in many different situations (Wikipedia, 2012). In (Cloutier R. , 2009) a pattern is described as a model or facsimile of an actual thing or action, which provides some degree of representation (an abstraction) to enable the recreation of that entity over and over again. He describes systems engineering/system architecture pattern as models which capture a high-level structure, appropriate to the design of the major components of a system. Furthermore in (Erl, 2009) states that the simplest way to describe a pattern is that it provides a proven solution to a common problem individually documented in a consistent format and usually as part of a larger collection. The notion of patterns originated with the (building) architectural patterns of Christopher Alexander (Larman, 2004). Further, in the same reference, it is stated that patterns for software originated in the 1980s with Kent Bent, who became aware of Alexander's pattern work in architecture, and then were developed with Ward Cunnigham at Tektronix.

In Center for Patterns and Systems Engineering (Cloutier R. , 2009), music demonstrates repeating patterns to make it easier to learn the tune. Three childhood songs have the same tune – Twinkle, Twinkle Little Star; Baa, Baa Black Sheep and The Alphabet Song. All are from the same Mozart tune. Mathematics is full of patterns –

methods to solve similar problems: sum of squares, quadratic equations, and standard integration of common functions. The use of cul-de-sacs by civil engineers/architects in a housing development is another example of a commonly found pattern. Other examples of patterns are geometric forms – a large circle and a small circle differ only by the radius. Patterns have been around in the engineering community for quite some time. Most notably, parts of the software community have been using them for years. The existence of patterns is almost universal. One can find patterns everywhere and the human mind seems to perceive patterns without conscious thought. Cloutier further explains that patterns express relation between the context, a problem, and a solution, and document the system attributes and usage guidance. They are time-proven in solving problems similar in nature to the problem under consideration.

The notion of a pattern as described in (Erl, 2009) is already a fundamental part of everyday life. Thomas Erl states that without acknowledging it each time, we naturally use proven solutions to solve common problems each day. Patterns in the IT world that revolve around the design of automated systems are referred to as design pattern.

As stated in (Dong, Zhao, & Sun, 2009) , design patterns have emerged to become an important design guidance that provides good generic solutions to recurring problems. Each design pattern documents a guideline in the software development process and leaves room for application variations.

In (Ambler, 1998), Scott described process pattern as a collection of general techniques, actions, and/or tasks (activities) for developing object-oriented software. Scott describes three types of process patterns conducted in organizations: Task process

patterns, Stage process patterns, and phase process patterns. He described task process pattern as pattern that depicts the detailed steps to perform a specific task, such as the Technical Review and Reuse First process patterns. Furthermore, he describes stage process as the pattern that depicts the steps, which are often performed iteratively, of a single project stage. A project stage is a higher-level form of process pattern, one that is often composed of several task process patterns. He describes phase process patterns as pattern that depicts the interactions between the stage process patterns for a single project phase, such as the Initiate and Delivery phases. In Figure 3, the program stage of process pattern is depicted. Scott shows that there is more to this stage than simply writing source code.

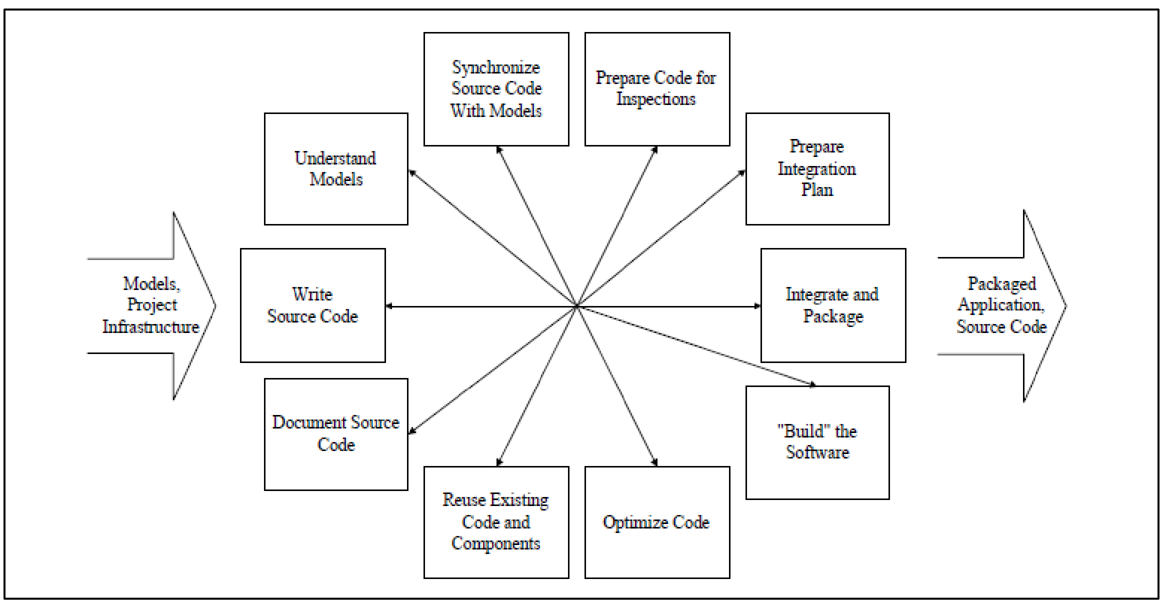

Figure 3. Process Pattern

Design patterns are recurring solutions to software design problems you find again and again in real-world application development. Patterns are about design and interaction of objects, as well as providing a communication platform concerning elegant,

reusable solutions to commonly encountered programming challenges (Data & Object Factory, LLC, 2001-2013). The three categories of the Gang of Four patterns generally considered the foundation for all other patterns are presented here as described in (Gamma, Helm, Johnson, & Vlissides, 1994). They are categorized in three groups: Creational, Structural, and Behavioral.

Creational Patterns

The creational patterns are ones that create objects for you, rather than having you instantiate objects directly. This gives your program more flexibility in deciding which objects need to be created for a given case. These include abstract factory, builder, factory method, prototype, and singleton. Figure 4 below shows the structure of the builder pattern. The Build pattern separates the construction of a complex object from its representation so that the same construction process can create different representations.

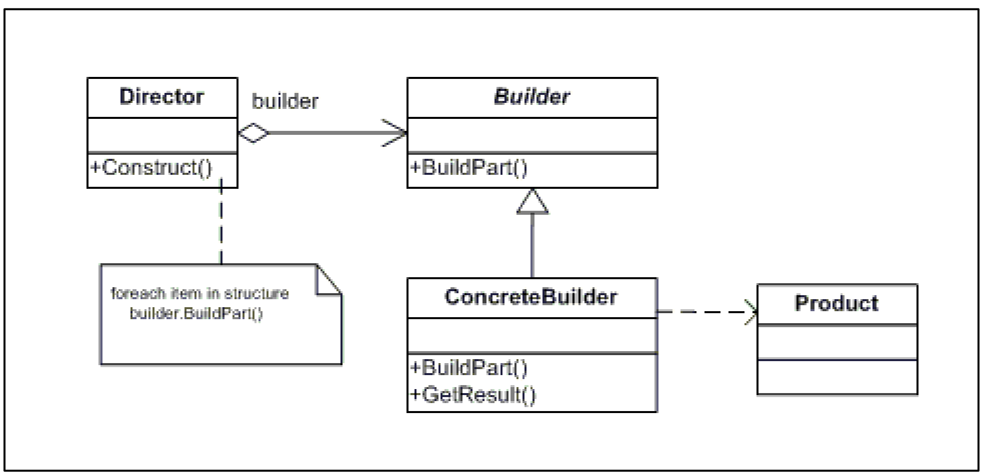

Figure 4. Build Pattern

Structural Patterns

The structural patterns deal with the composition of classes or Objects. The structural patterns included Adapter, Bridge, Composite, Decorator, Facade, Flyweight,

and Proxy. As an example, Figure 5 is presented here for structural adapter pattern. The adapter pattern converts the interface of a class into another interface clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces.

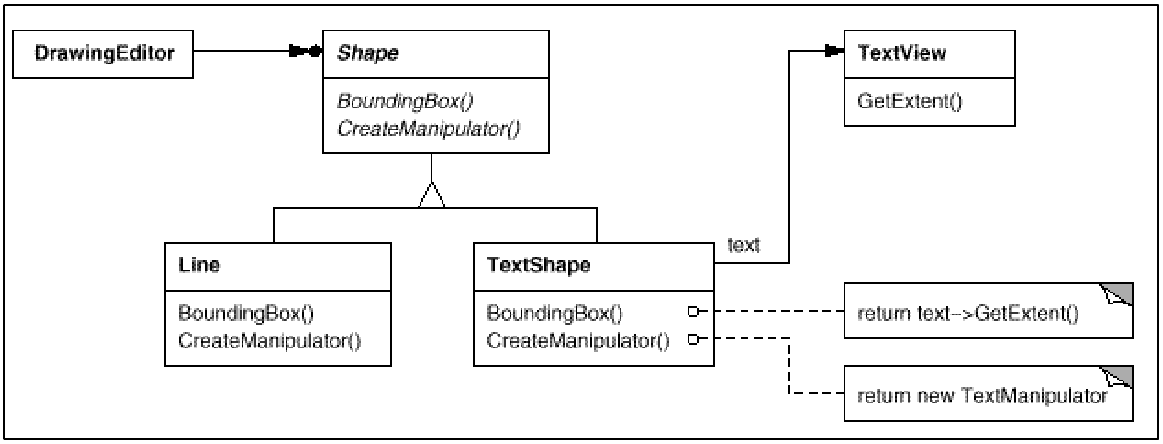

Figure 5. Adapter Pattern

Behavioral Patterns

Behavioral patterns characterize the ways in which classes or objects interact and distribute responsibility. Behavioral patterns as identified and described by GoF include Interpreter, Template Method, Chain of Responsibility, Command, Iterator, Mediator, Memento, Observer, State, Strategy, and Visitor. The structural presentation of the interpreter pattern is depicted in Figure 6. The interpreter pattern is described as the grammar and interpretation of a language.

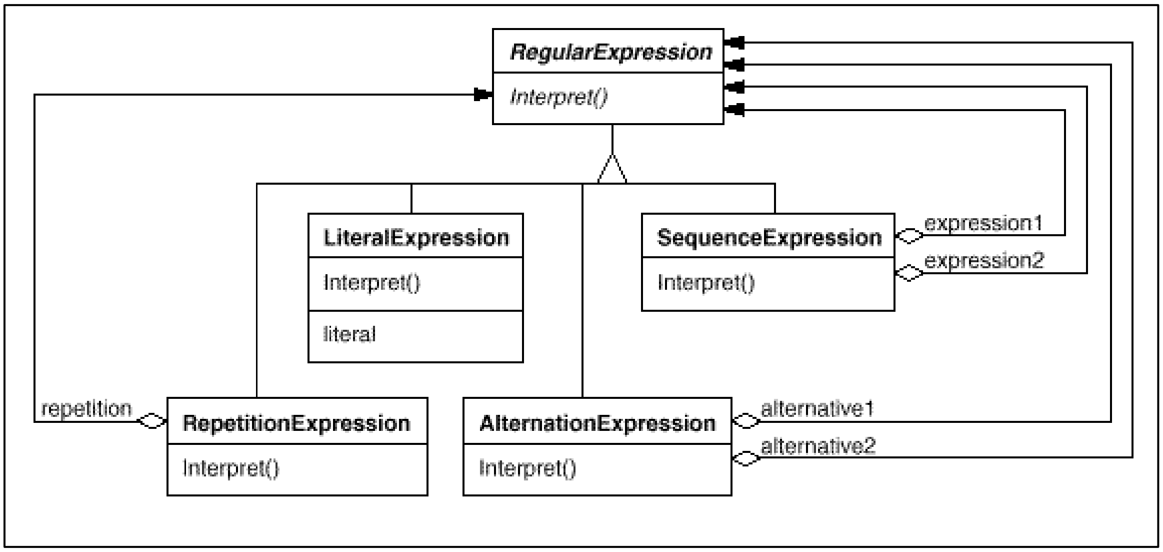

Figure 6. Interpreter Pattern

Patterns in Enterprise Software

In recent years there has been a small but useful growth in describing patterns for the development of enterprise systems (Fowler, 2005). Two kinds of enterprise software patterns will be discussed: Patterns of Enterprise Application Architecture and Enterprise Integration Patterns.

Patterns of Enterprise Application Architecture

Martin Fowler in his Patterns of Enterprise Application Architecture provided a list of the patterns used in enterprise application architecture. The pattern categories discussed include Domain Logic Patterns, Data Source Architecture Patterns, Object-Relational Behavioral Patterns, Object-Structural Patterns, Web Presentation Patterns, Distribution Patterns, Offline Concurrency Patterns, Session State Patterns, and Base Patterns. Figure 7, is an example of enterprise application architecture pattern from Domain Logic Pattern. It shows a domain model pattern that creates a web of

interconnected objects, where each object represents some meaningful individual, whether as large as a corporation or as small as a single line on an order form.

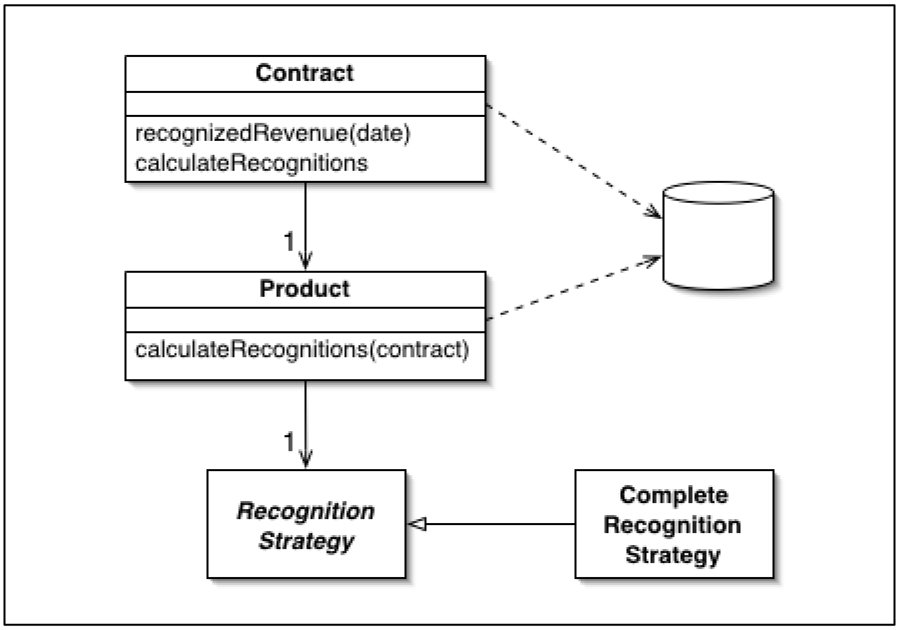

Figure 7. Domain Model Pattern

Martin Fowler work concentrated on Enterprise Application Architecture in the context of a layered architecture.

Enterprise Integration Patterns

Integration of messaging system is discussed in (Wolfe & Hohpe, 2004). In this book, integration means connecting computer systems, companies, or people. Based on this meaning, there are six types of integration: Information portals, data replication, shared business functions, service-oriented architectures, and distributed business processes. Examples of patterns used in messaging systems are provided here. Messaging system manages messaging the way a database system manages data persistence. Messaging system is needed to move messages from one computer to another because computers and the networks that connect them are inherently unreliable. Some of the

patterns included in messaging system include Request-Reply pattern (Figure 8), Multiple Consumers, Return Address, Multiple Service Providers (Figure 9), Correlation Identifier, and Pipes-And-Filters.

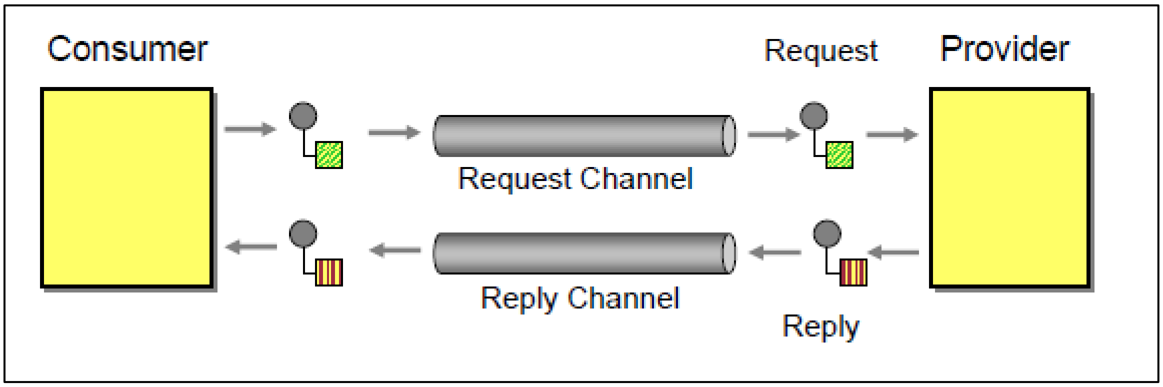

Figure 8. Request-Reply pattern

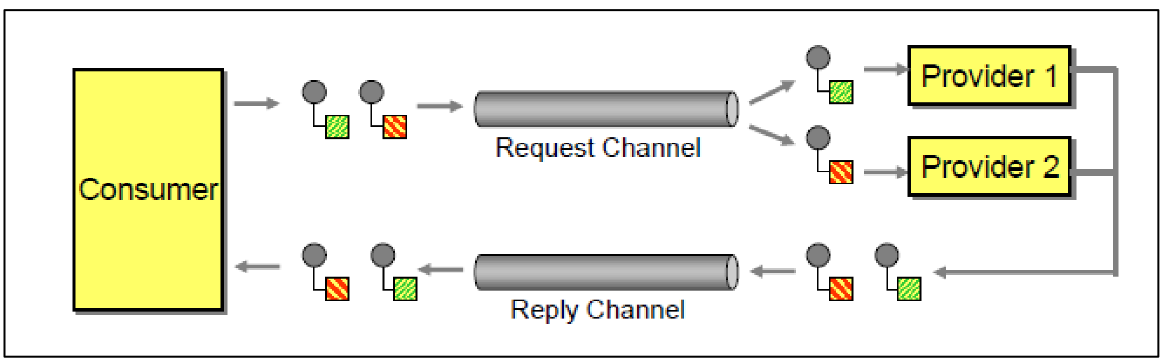

Figure 9. Multiple Service Providers

There are drawbacks and benefits for using patterns. The following are some of the benefits and drawbacks identified in (Dong, Zhao, & Sun, 2009) , (Cloutier R. , 2009), and (Erl, 2009).

Benefits for Using Design Patterns

- **Design Reuse:** Design patterns are suitable for reusing design experience at a high abstraction level. Patterns allow the designers to tackle the same problem by

reusing expert solutions. Patterns enable reuse of good concepts and implementations, and to preserve them for future projects.

- **Adaptability and Extensibility:** Software developers adopt patterns in their design to improve adaptability and extensibility.

- **Documentation of Design Solutions and Tradeoffs:** Design patterns generally document the design decisions and tradeoffs as well as possible ways for future evolutions.

- **Design Consistency:** Can be used to ensure consistency in how systems are designed and built. Consistent application tends to naturally improve the quality of system designs.

- **Design Standard:** Can become the basis for design standards. Architectural patterns may help control the complexity of architecture by standardizing it on a well-known and practiced pattern.

- **Educational Aids**: Can be used as educational aids by documenting specific aspects of system design (regardless of whether they are applied).

- **Common Understanding:** Describing parts of the architecture in the context of known and understood architecture patterns results in a common understanding of the architecture.

- **Mitigate Risks:** Using and applying known architecture patterns in architecture design introduce less risk than a new architecture design.

Drawbacks for Using Design Patterns

- It is hard to understand the systems since the original design decisions and tradeoffs embedded in the design patterns are not available.

- Due to lack of documentation, high-level architecture and design information is often missing in system implementations, particularly for legacy systems.

- Over time, similar designs are arrived at independently by different designers on various projects.
- The design reuse prevents engineers from having to reinvent, or rediscover the same concept and provides a common vocabulary for the design concepts that a project can share.

Summary

As opposed to other areas, patterns have been developed and effectively implemented in software engineering field. The patterns studied were presented in terms of their, structure, context, problem part, and solution part. As determined during literature review, work has already begun of identifying and applying patterns in other areas including systems engineering. The literature review covered development and use of patterns mainly in software field. It was observed that similar methods and approach in developing patterns for software applications can also be used in developing patterns for other areas including T&E process, systems engineering, and hardware design. The benefits and drawbacks of using patterns were also identified. The literature review also included the identification of challenges commonly faced by T&E communities. These challenges were determined through informal peer survey and review of prior project work at a T&E organization. The development and appropriate application of identified T&E patterns leads to resolving the identified challenges.

III. METHODOLOGY

Chapter Overview

The methodology used to develop patterns for T&E operations is described in this chapter. Mainly the methodology is observational consisting of review of current and past T&E projects to identify and describe patterns. The patterns identified using this methodology are presented in the format shown in Table 3. This is the format used in the Design Patterns book (Dougherty, Sayre, Seacord, Svoboda, & Togashi, 2009) to describe the 23 pattern types grouped in three pattern categories: creational , behavioral, and structural.

Table 3. Pattern Elements

Pattern Element	Element Description
Pattern Name and Classification	A descriptive and unique name that helps in identifying and referring to the pattern
Intent	Goal behind the pattern and the reason for using it
Also Known As	Other names for the pattern
Motivation (Forces)	A scenario consisting of a problem and a context in which this pattern can be used
Applicability	Situations in which this pattern is usable; the context for the pattern
Structure	A graphical representation of the pattern
Participants	A listing of the objects used in the pattern and their roles in the design.
Collaboration	How objects used in the pattern interact with each other
Consequences	The results, side effects, and tradeoffs caused by using the pattern
Implementation	Implementation of the pattern; the solution part of the pattern
Known Uses	Examples of real usages of the pattern
Related Patterns	Other patterns that have some relationship with the pattern; discussion of the differences between the pattern and similar patterns

(Dougherty, Sayre, Seacord, Svoboda, & Togashi, 2009)

Identification

Patterns are identified based on the familiarity of T&E projects to the person developing them. The experience of the developer with T&E projects helps in discovering patterns in T&E. Due to repeatability of the processes conducted to achieve

T&E objectives, over time patterns are observed as the similar projects with related requirements and objectives are completed. The patterns identified in this thesis were repeatedly observed to occur to all the projects conducted in the organization. Unfortunately, the organization executing the processes may not recognize them as patterns resulting to wasted resources every time a project is conducted. Another way to the patterns are identified is the review of completed test plans and project reports and study of their requirements. The reports would include consisted formats indicating some kind of pattern used in writing them. Additionally, some of the contents of each test plan or report would be consistently similar to test plans and reports of different projects indicating their similarity to some extent hence use of patterns. Reviewing the test plans and reports and understanding the requirements for each project, patterns can be seen in the approach of accomplishing the test objectives. For instance, test plans would resource requirements. Planning, execution, and reporting processes are the main phases in T&E process. They form the backbone of every pattern developed for each T&E project.

The following main T&E processes consist of specific tasks and documentation requirements that are included in each of the identified T&E patterns.

T&E Planning

Operational Test (OT) planning is one of the most important parts of the OT&E process. Proper planning facilitates the acquisition of data to support the determination of the weapon system's operational effectiveness and suitability. Planning must be pursued in a deliberate, comprehensive, and structured manner. Careful and complete planning may not guarantee a successful test program; but inadequate planning can result in

significant test problems, poor system performance, and cost overruns (Claxton, 2005). During T&E planning, key processes and documentation are completed. These processes and documentation are completed either consecutively or concurrently to meet requirements. The documentation requirements include statement of work (SOW), rough order of magnitude (ROM), test plan (TP), work unit assignment (WUA), standard operation procedure (SOP), safety releases (SR), operational risk management (ORM), cost estimate (CE) and data collection Plans (DCP). The processes include conducting work acceptance review (WAR), developing timeline, developing operation plan (OpPlan), coordination with all the stakeholders, participating in test readiness review (TRR) and content review boards (CRB), and identifying and reserving resources required for the test.

T&E Event Execution

An OT plan is only as good as the execution of that plan. The execution is the essential bridge between test planning and test reporting (Claxton, 2005). Prior to commencement of event execution, the necessary test resources are identified and reserved. These include personnel requirements, equipment requirements, logistics requirements, facilities requirements, and funding requirements. In order to be successful in the execution and meet sponsor’s requirements, the coordination of these requirements requires a systematic approach. This approach is repeated many times for each project to the point where the personnel performing it start seeing patterns. When a project calls for certain skills, the manager or project lead approaches the resource manager to determine who is well suited to support the task. Likewise, when a project requires certain

equipment, the resource manager looks at the equipment inventory to determine if the equipment is available to support the project. This process is repeated with all other project requirements and in every project to the point where clear patterns are followed without the knowledge of the performers. During the operations more patterns are observed. The operations such as surveying, equipment setup, test execution, and cleanup are consistently repeated for each project. Each of the tasks is completed per procedures established by the organization or as per requirements of the project. The repeatability of the procedures and the frequency of each task during multiple projects results to observed patterns. The patterns develop as these named tasks are performed to provide solution to problems anticipated during test operations. For instance, surveying is conducted to obtain equipment setup locations to ensure valid data collection. Appropriate equipment set up ensures smooth operations with fewer risks. Cleaning up includes clearing the range of all test equipment and any hazardous or non-hazardous waste generated during the operations, returning equipment for repair and storage, and personnel retrograde to home commands.

Reporting

Upon completion of test execution and data validation, reduction, and analysis reporting phase begins. Reporting includes incorporating the data analysis results to established report templates. The templates used are repeatedly used for different projects with slight tailoring to fit each project's requirements and specifications. During this reporting phase the following are accomplished: validation of raw data, reduction of raw data, data analysis, preparation of draft test report, peer review of draft report, completion

of test report, publishing of final report, delivery of test report to sponsor, archiving of test report for future reference. Data validation ensures that the correct and complete data is available. The data reduction is performed prior to analysis and includes cleaning up the data to enable easier analysis. Data analysis results showing are incorporated in the test report and are used by the decision makers to determine if the project objectives have been met. The final report submitted to the sponsor consists of standard sections for each project. It includes system description, test results, conclusions, and recommendations. The test report must communicate the results of completed tests to decision authorities in a timely, factual, concise, comprehensive, and accurate manner (Claxton, 2005).

Description

Description is the second and last part of the pattern development methodology. Each pattern identified satisfies the three main pattern parts: pattern name, problem, and solution. A pattern name is a descriptive and unique name that helps in identifying and referring to the pattern. As observed in Introduction Chapter, a pattern is described as a named and well-known problem/solution pair. In this thesis, each identified pattern was named and their problem/solution pair identified. The names were selected based on the kind of pattern identified. For instance, a pattern presenting Cost Estimating process was simply named Cost Estimate and a pattern presenting the three primary phases in T&E process was simply named Primary.

The test subjects in this thesis are the various patterns developed. In results section the patterns are demonstrated in form of their structure and purpose. The structure shows each part of the pattern and its relationship with the other parts.

IV. RESULTS

Chapter Overview

This chapter presents the results obtained from this investigation. The results include the presentation of various patterns identified and associating each of the patterns with the corresponding T&E challenge to be resolved using the pattern.

T&E Patterns

Based on T&E operations and challenges encountered during the operations, eight T&E patterns have been identified and described in this thesis. The patterns are in three categories as used for the 23 patterns of the GoF. These categories are creational, behavioral, and structural. In this thesis, five behavioral patterns, one creational pattern, and one structural pattern were identified. Table 4 shows a list of the patterns identified.

Table 4. T&E Patterns

Pattern Category	Pattern Name	Problem	Solution
Behavioral	Primary	What are major T&E processes?	Complete the planning, execution, and reporting phases in every T&E project
	Objective	What are project objectives and how are will they be achieved?	Identify sponsor requirements and conduct T&E operation to achieve project objective
	Cost Estimating	Are the project costs correctly identified and funds assigned?	Conduct cost estimate based on sponsor requirements to determine the cost for travel, material, and labor
	Schedule	Are project events and documentation completed in a timely manner?	Based on sponsor requirements and resource availability, determine the appropriate schedule for all project events
	Work Acceptance Process	What work/T&E projects should an organization accept?	Review the Statement of Work to determine appropriate capabilities to accomplish the project objectives
	Risk Management	Are the projects correctly managed?	Develop and implement a risk management plan
Creational	Hazard Control	How procedures can help to avoid hazards during operations	Create and follow a standard procedure to control hazards during operations
Structural	Test Team	Who is supporting the test?	A test team is developed with appropriate skills to accomplish test objectives.

Behavioral Patterns

Name: Primary Pattern

The primary T&E operation pattern consists of the three main phases of the T&E operation. These phases completed sequentially in each operation include planning, execution, and reporting. Planning encompasses all the necessary preparation prior to subsequent processes. As discussed previously, preparation includes selection of test item(s), establishment of test procedures, selection of test site, selection and training of test personnel, preparation of test facilities and resources, the acquisition of support equipment, and test supply support. Execution involves conducting the actual test to determine system performance. The main events during execution phase include traveling to the test site, setting up the appropriate data collection equipment, conducting the test execution per the test plan, and collect the type and amount of required data. The reporting phase consists of data validation, data reduction, data analysis, and report writing. The data validation is performed to ensure that the valid data was collected. Reduction is cleaning up of data prior to analysis. Once the data is analyzed using statistical methodology and other appropriate techniques, the results are incorporated in the formal report and delivered to the sponsor.

Intent: The three major processes in the T&E effort are planning, execution, and reporting. In every T&E event, these processes are repeated in the following order: planning → execution → reporting.

Also Known As: Not applicable (n/a).

Motivation (forces): As simple as in everyday life, human beings are constantly thinking first (planning) before reacting (execution) and getting results of their actions (reporting).

In the T&E this pattern is always performed regardless of the level for each project. The completion of the pattern is an assurance that the Operation has been conducted appropriately.

Applicability: This pattern is applicable in everyday life in all activities where a reportable successful operation is expected. All the T&E events in DOD requires planning, execution, and reporting; planning to ensure successful execution, execution to test system capability, and reporting to test the capability of the system.

Structure: The graphical presentation of the Primary T&E Operation Pattern is shown in Figure 10.

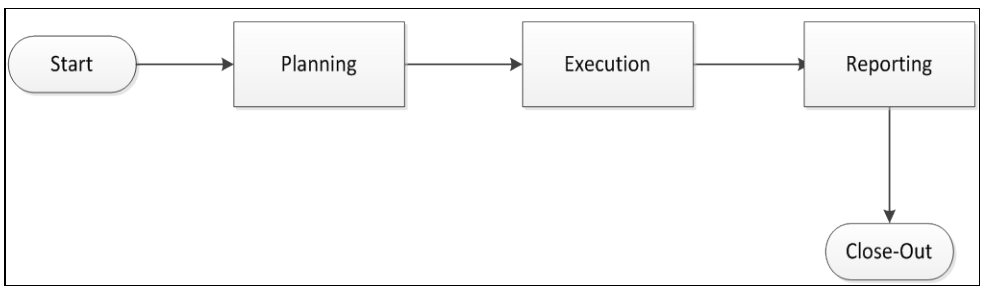

Figure 10. Primary Pattern

Participants: The participants in this pattern include planning, execution, and reporting.

- Planning – planning is the first step in T&E Operation. It includes all the necessary preparation prior to execution.
- Execution – Test execution includes executing a test, collecting data, conducting data reduction, validation, and analysis, and conducting a data review to ensure data is adequate to support evaluation.
- Reporting – reporting is the final step in this pattern. It is the step immediately before project close-out.

Collaboration: The three phases collaborate with each by order of precedence to accomplish the pattern's objective. The phases are completed sequentially starting with planning.

Consequences: Using the pattern leads to streamlined Operation to efficiently and effectively conduct the T&E events. However, as mentioned in previous section, there are tradeoffs for using the pattern.

Implementation: The implementation of this pattern is observed in all projects undergoing T&E phase of acquisition frame work.

Known Uses: This is the primary pattern used while supporting a T&E effort.

Related Patterns: Related patterns are the patterns developed from individual Operations of this pattern. This primary pattern is included in all other patterns as it will be shown here.

Name: Objective Pattern

The objective pattern consists of all the necessary steps performed to achieve the objective of the T&E operation. For instance, a Service Life and Accelerated Age test for Time Blasting Fuse Igniter (M760) was conducted to update the Operational Reliability and Service Life Projection. The objective for this test was to update the R_o and SLP of the item and was achieved by using the objective. The pattern presents the steps necessary to meet the T&E objective efficiently and effectively. These steps include ensuring that complete documentation required for the test is available and that all the test processes have been considered and correctly planned for. For instance, SOW is first received by the testing agency from the sponsor to determine customer requirements

(T&E objective). The inputs to the SOW include customer requirements, test requirements, and kick-off meeting guidance. The testing organization then develops a WUA stating the tasks to be accomplished to meet the test objective. The WUA inputs include cost estimate and SOW. Additionally, the WUA provides the estimated cost, deliverables, and the due dates for each deliverable. Once the sponsor signs the WUA, the testing agency develops a test plan along with a standard operating procedure (SOP) to be used during the execution of the test.

***Intent*:** this pattern is used to ensure that the test objectives are met. It is a pattern composed of steps necessary to accomplish the test objective. The test objective is to test the system in accordance with customer's specifications to determine to if the system requirements are met.

Also Known As: n/a.

***Motivation (Forces)*:** All the T&E events have one objective in common: testing system capability. The desire to test the system per customer's specifications and requirements drives the need and usage for this pattern.

***Applicability*:** This pattern is applicable in all T&E events conducted for DOD systems.

Structure: The pattern in Figure 11 shows the flow process of achieving the T&E objective. It includes the main processes and documentation.

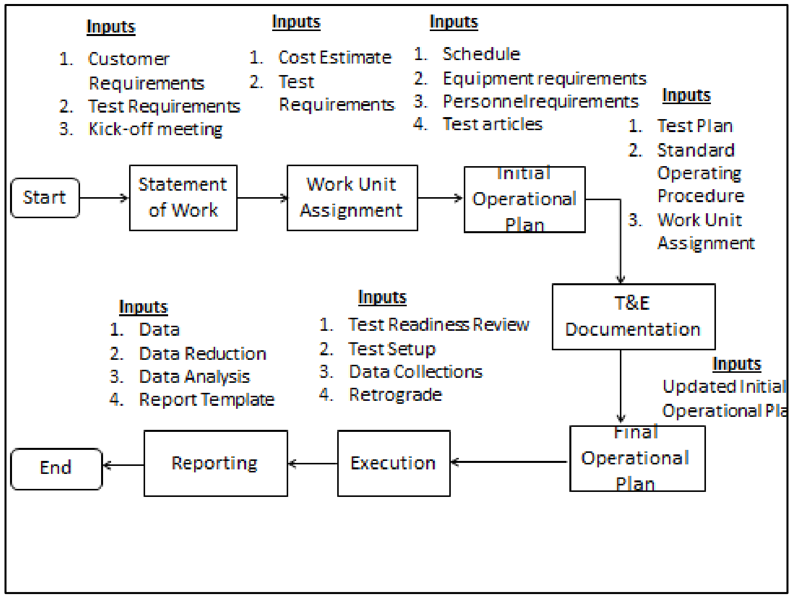

Figure 11. Objective Pattern

Participants: As described in the solution paragraph and as shown in the structure, the participants (as shown in the structure above) include test plan, Op Plan, SOP, Timeline, Test report.

The test plan provides detailed information about the test objective, system description, schedule, test personnel information, test execution procedure, test samples, and data forms and data collection requirements.

The OpPlan is a planning tool prepared in SharePoint for tracking the status of project planning. It is reviewed and approved by the management team prior to test execution. It includes project name, estimated test dates, equipment requirements, personnel requirements, test samples requirements, final project documentation, and Op Plan Checklist. It also includes a comments section to gather comments and remarks provided by stakeholders including the Op Plan reviewers and approvers. The review and approval process is initiated by the PL once he has confirmed that every action item

in the checklist has been completed. Through signature flow process, the Op Plan is subsequently sent to all the reviewers and approvers.

Standard Operating Procedure (SOP) is a safety documentation that contains procedures to be followed during T&E event for safe operation to avoid injury to personnel or damage to equipment. It includes a hazard analysis table consisting of all the identified potential hazards. Prior to starting of operation, a safety brief is conducted to ensure that test participants are aware of the potential hazards.

In addition to OpPlan, the PL is expected to develop a timeline showing the amount of time each step of the T&E Operation takes. For instance, it will show the number of days required to complete preparing a test plan. It also shows the cumulated amount of time at every step of the process from planning to reporting.

Collaboration: The objects in this pattern work together to achieve the test objective. Sometimes the objects (documents) are references to each other.

Consequences: Using this pattern leads to a standard and more effective and efficient method of achieving test objectives of current and future projects. it helps plan, execute, and report on T&E operations with less resources since every time the process is conducted is reusing already established method that has been used many times. The test team will spend less time and funds during planning, executing, and reporting for a new project if the pattern is effectively implemented. Furthermore, use of this pattern results to fewer mistakes as the steps in the pattern have been conducted before and have been mastered. Contrary, using the pattern discourages innovation. For instance, the organization will be reluctant to invest in investigating to new methods as long as the

current methods are working sufficiently. This results to an organization and workforce with no opportunity or motivation of improving their process.

Implementation**:** This pattern is used to determine test objective. It ensures that effective method is employed to assure successful execution of T&E operation as expected by the sponsor. Proper implementation of this pattern during all phases of T&E operation could result to a more successful and efficient operation.

Known Uses: This pattern is used during the planning, execution, and reporting of most DOD T&E Operations.

Related Patterns: The related are all the T&E patterns included in this methodology section.

Name: Cost Estimate Pattern

Cost Estimate (CE) is conducted upon acceptance of the rough order of magnitude (ROM) by the customer to determine the amount of funds required to complete the T&E operation. The command approve template consisting of formulas to calculate the labor amount using the correct current Fiscal Year labor rates is used to develop the CE. The template consists of the three phases of the T&E operation: Planning, Execution, Reporting. Labor, travel, and material costs are estimated for each phase. The labor portion is broken out into the number and specialty of the personnel supporting the project, the number of days and the number of hours per day each personnel category will be working until the completion of the assignment. Additionally, the two labor types, government and contractor support, are calculated separately to ensure the appropriate type of funds are determined. The travel portion consists of the per diem, lodging, and

mode of transportation expenses based on the travel requirements and mainly controlled by the amount of travel and location of the T&E events. Lastly, the material and equipment costs are included if any required for T&E support. The summary of funds showing the break-out of funds into labor, travel, and material for both government and contractor support is incorporated into the Work Unit Assignment.

Intent: This pattern ensures that the cost estimate for the project is correctly done to ensure availability of funds to support the T&E project.

Also Known As: N/A

Motivation (Forces): There always limited funds to execute DOD events. Organizations are always encouraged to do more with less. Additionally, when bidding for T&E project, usually there is more than one qualified testing agency and usually the least expensive once gets the work. A good CE is the starting point to determine how much money is enough, and not a penny more, to accomplish test objective.

Applicability: This pattern is applicable in all projects that will require funds to conduct; usually all the DOD projects.

Structure: The cost estimate template is used to determine the cost for completing the project tasks. Figure 12 presents the cost estimate structure showing documentation and process requirements to obtain correct amounts for each cost element; travel, labor, and material.

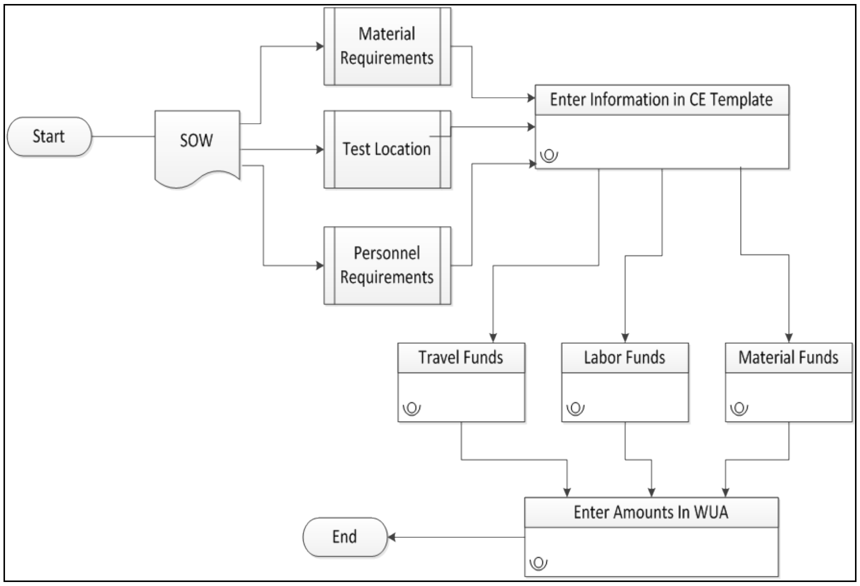

Figure 12. Cost Estimate Pattern

Participants: The participants in this pattern are all the factors considered in developing a good CE. These include labor hours, travel expenses, and material expenses, test phases (planning, execution, reporting).

Collaboration: Objects collaborate to achieve the best results. For instance, they obey the precedence rule; planning estimate is completed prior to execution estimate while the reporting estimate is completed after the execution estimate. Additionally, the objects can give or take depending on the PL's requirements to ensure a good estimate. For instance, if the travel requires more than calculated, the labor object can be reduced to meet the travel object's requirement.

Consequences: As previously mentioned, using any pattern has consequences; good or bad. Using CE pattern prevents mistakes that could lead to underestimating or overestimating of a project. Also, it saves time during development of a new CE usually what needs to be done is to change a few things and adjust numbers based on the requirements of a new project.

Implementation: CE pattern is used in all projects. CE ensures that all the cost requirements for the project have been accounted. A good CE alleviates the cost challenges previously discussed. The risks of running out of funds before the project is completed are significantly reduced when a good CE pattern is used in all projects and especially with new and unfamiliar projects.

Known Uses**:** This pattern is used during the planning of a new project. It is used to determine the amount of funding is required to complete all the project tasks.

Related Patterns: No other patterns are related to this.

Name: Schedule Pattern

The schedule pattern solves the problem: what is the required test schedule to complete the test objectives in a timely manner? The solution will include determining schedule based on test requirements, collaborating with all the stakeholders, developing an effective timeline, developing an operations plan on Microsoft SharePoint while considering all the risks to include scope creep, weather, lack of funds, insufficient personnel, equipment support, etc. Test schedule starts when the project is initiated and is usually adjusted as required and possibly during the execution of T&E operations. Schedule pattern includes the accounting of all the actions and their assigned execution durations. The Operations Plan and timeline are good resources during development and tracking of schedule. The OpPlan shows all the action items to be completed during planning of the T&E prior to test execution while the timeline shows the start and completion times of all the steps in the T&E operation.

***Intent*:** Test schedule pattern allows easier scheduling of test functions by following an established and repeatable process. Scheduling pattern ensures that the organization uses a known process of scheduling that guarantees completion of projects tasks in a timely manner.

***Also Known As*:** Test schedule is also known as a Period of Performance because it shows the overall duration the funding will be available to complete the project.

Motivation (Forces): Test scheduling pattern is driven customer requirements, project requirements, and resource availability. The customer usually indicates in the SOW the period they expect to receive test deliverables (test plan, test report, etc.). The test schedules will be developed so as to meet the dates specified by the customer. Additionally, test scheduling will be developed based on the project conducted. For instance, scheduling for a small project requires less work than scheduling for a big and complicated project. Finally, the availability of resources is a major factor affecting the scheduling of projects. For example, two tests using similar resources such as test equipment, ranges, personnel, etc., will be scheduled at different times to avoid resource constraint.

Applicability: Scheduling pattern is applicable in all T&E operations. It is applied during planning phase to ensure that all the necessary preparations have been completed prior to execution of test. During execution phase, scheduling of events is at most importance because it ensures a collection of valid data for analysis to determine system's capabilities.

Structure: Scheduling pattern in Figure 13 encompasses the steps and milestones of the project.

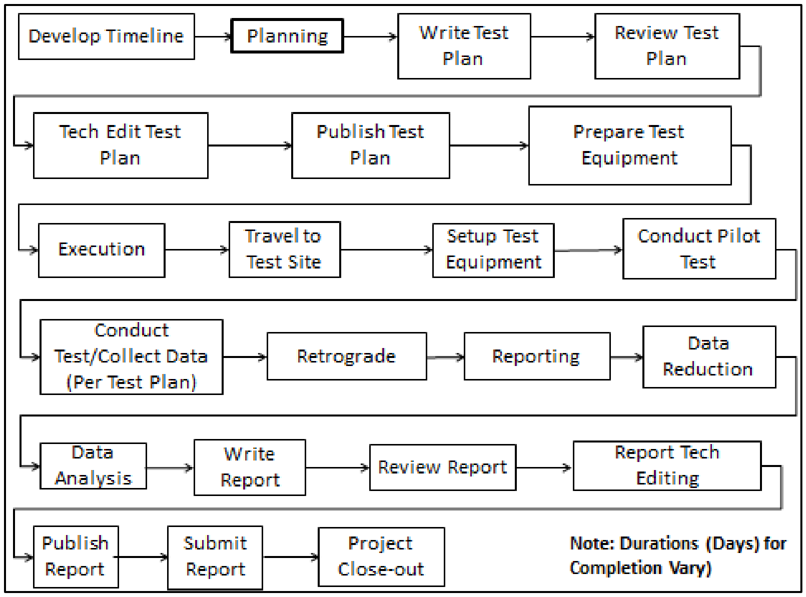

Figure 13. Scheduling Pattern

Participants: Participants in scheduling pattern include resources scheduled, milestones, tasks planned, tasks completed, upcoming tasks, dates, and durations for task completion.

Collaboration: Availability of resources ensures completion of planned tasks hence achievement of milestones as required by the testing agency. The dates to start and complete the planned tasks will be shown on the schedule. Milestones are achieved when tasks are completed as reflected in the scheduling pattern. The duration for each task is determined by the start and end dates assigned.

Consequences: Using the scheduling pattern ensures that the major project actions are scheduled appropriately to avoid any delay of deliverables to the sponsor. The project leader saves a lot of time that is used in completing other project actions by using the scheduling pattern. Additionally, the scheduling pattern provides the project leader with a peace of mind knowing that there is no risk of schedule slip since the pattern has been successfully used with past projects.

Implementation: This pattern is implemented during all the phases of the T&E operations. The timely completion of scheduled events relies on an effective scheduling pattern. It is advisable to use it all the time for consistency and assurance for success.

Known Uses: Used during the scheduling of T&E events. This pattern is useful when planning, executing, reporting, and closing out of all DOD T&E operations to avoid schedule delays, cost overruns due to schedule slip, and loss of key T&E personnel due to reassignments at the end of initially set period of performance.

Related Patterns: Test schedule pattern works with the collaboration of other T&E patterns. The schedule pattern is developed upon completion of Test Objective pattern.

Name: Work Acceptance Process Pattern

DOD is a complex organization with innumerable systems requiring to undergo T&E prior to transitioning to the warfighter. Each of these systems has specific T&E requirements that require skills and capabilities to meet. The Work Acceptance Process determines if the resources and capabilities are available to meet the test requirements. This is done by conducting a work acceptance review with attendance of the project leader, program manager, and select organizational management team members.

Intent: The pattern ensures that a consistent process is used all the time during the acceptance of T&E project.

Also Known As**:** n/a.

Motivation (Forces): DOD is a complex system consisting of many agencies, systems, and a large workforce. Among the agencies are T&E agencies responsible for testing and evaluating systems prior to transitioning to the warfighter. A successful T&E

organization is equipped with capable workforce and equipment for conducting the T&E operations. This pattern is developed to ensure that the organization is well equipped to test and evaluate the systems provided by the developing sponsor.

Applicability: This pattern is applicable in all projects and as soon the sponsor provides a statement of work to the testing organization.

Structure: The work acceptance process is provided in Figure 14.

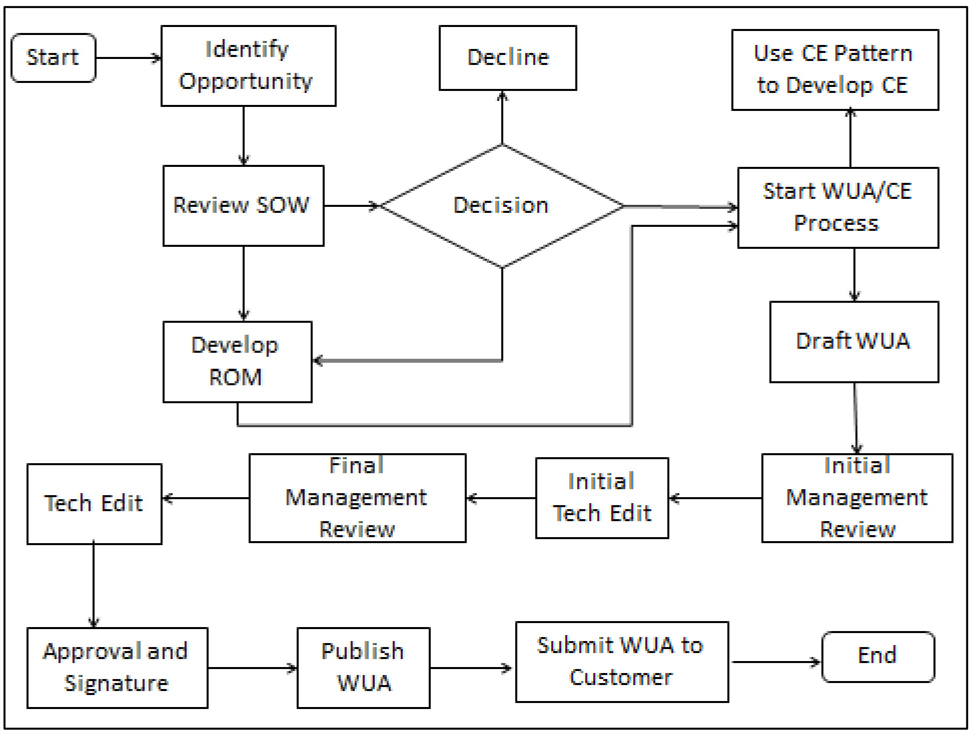

Figure 14. Work Acceptance Process Pattern

Participants: Participants in this pattern include work type, customer requirements, documentation requirements, and review process.

Collaboration: During the work acceptance process, the work type is evaluated by the management to determine if is supportable by the organization. The customer requirements are related to the type of work received. For instance, Surveillance Testing will have customer requirements such as determining or updating the Service Life

Projection and Operational Reliability. The review process is conducted by referring to the documentation requirements and customer requirements.

Consequences: There are a lot of benefits for using this pattern. First, the right and supportable work is accepted and the required documentation for funding is prepared in a timely manner before the period of performance starts.

Implementation: This pattern is implemented in the acceptance of all new work in the organization.

Known Uses: Organization use this pattern to ensure that the work performed is supportable based on the capabilities of the organization.

Related Patterns: n/a.

Name: Risk Management Pattern

Risk management pattern is a behavioral pattern developed to effectively manage project risks. Risk management is application of skills, knowledge, and risk management tools and techniques to your projects to reduce threats to an acceptable level while maximizing opportunities (Heldman, 2012). Hilson and Simon in (Simon, 2012) describes risks as arising from uncertainty and they are about the impact that uncertainty events or circumstances could have on the achievement of goals. In Risk Management Guide for DOD Acquisition (Defense, 2006), risk is defined as a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints. This risk management pattern encompasses all the steps conducted to ensure a successful operation without impact of risks. The potential risks considered in risk management during a T&E operation include mismanagement of

funds, cost overrun, schedule slip, poor service or product quality, dissatisfied customers, damage to equipment, and injury to personnel.

Intent: This pattern provides an easier way to ensure that the operation will be conducted successfully with reduced risks. Use of the pattern provides the ability to reuse what has been used before and is believed to work. DOD testing organizations face potential shutdown if they fail to manage critical risks. For instance, risks resulting in death can result in a shutdown.

Also Known As: n/a.

Motivation (Forces)**:** The forces that drive the development of risk management include fear of failure, limited funds, limited time, sponsor oversight, critical project, customer expectations, desire for success without failure, and management support. Due to the mentioned forces that could lead to loss of business or failure to provide needed support to the warfighter, T&E organizations will be driven to follow a risk management plan that has worked before and guarantees success for current and future projects.

Applicability: Risk management pattern is applicable in the planning, execution, and reporting of all projects. It is also applicable to both small and big projects. Finally it is applicable all the time during the project lifetime.

Structure: Since identified risks are always reoccurring during operation and new risks are developed and identified during operation, risk management pattern is best presented as an iterative process. As described in (Denis, 2010), the structure in Figure 15 includes the following steps:

(1) Risk Strategy: Decision on how to manage risk throughout the duration of the operation

(2) Identify Risk: Identify what is the risk, and what is at risk.

(3) Allocate Ownership: Owner is best person positioned to perform mitigating actions on the risk and monitor the risk.

(4) Evaluate Risk: Evaluating and assigning the risk with an impact and probability score.

(5) Plan Mitigations: In a general sense, every risk has a standard set of mitigations which can be applied to it. These are commonly referred to as 'The 4 Ts':

   a. Transfer – transfer the risk to another party

   b. Tolerate – Do nothing option for risks with very low impact

   c. Terminate – Adjusting the program so the risk is no longer applicable to the program.

   d. Treat – Take actions to reduce the probability and impact of risk.

(6) Implement Actions: Concrete actions to the risk owner for risk management

(7) Monitor and Control: Review of risks and actions so the risk impact and probability can be updated following any actions which have been performed to treat them.

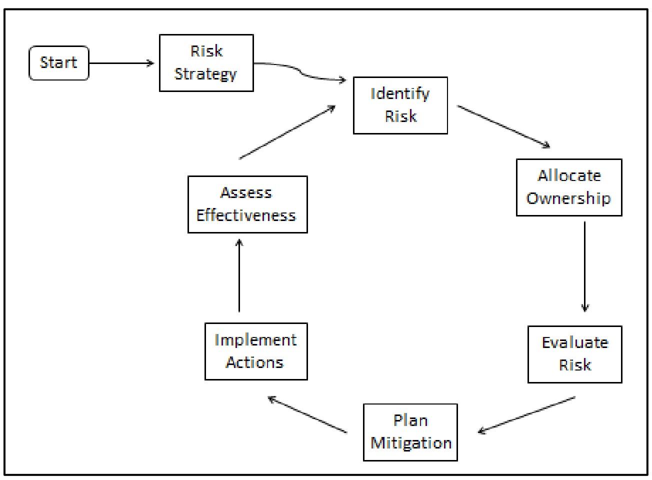

Figure 15. Risk Management Pattern

Participants: Participants in this pattern are the four main steps for risk management and the actions performed during each main step.

Collaboration: As the pattern structure shows, each main step is dependent of the completion of the preceding or succeeding one.

***Consequences*:** Using risk management pattern could result in many benefits that include less or no injuries, cost overruns, schedule slips, poor work quality, loss of equipment, and loss of skilled personnel. Contrary, using the pattern may result to increase in program costs because funds will be required to ensure consistency use of the pattern in all projects even in some would not require it.

Implementation: This pattern is implemented in the planning, execution, reporting, and closing out phases of all projects. The pattern is repeated in each phase to identify, analyze, and control all risks.

Known Uses: Risk management pattern is used all the time during risk management meaning all the time throughout the lifetime of the project.

Related Patterns: Hazard control is a related pattern to risk management pattern. In risk management, safety hazards are identified as some of the risks in a project that could result in increased cost and schedule slip if they are not effectively managed and controlled.

Creational Pattern

Name: Hazard Control

Hazards are controlled to ensure safe T&E operations. As it is impossible to identify all the risks associated with any project, it is also not possible to identify all the hazards in an operation. Organizations have established hazard analysis procedures to identify and mitigate operation hazards. For instance, in (CRANE, 2009), hazard

analysis is defined as the process of identifying and evaluating the hazards of a system, operation, facility, or item and then making change recommendations that would either eliminate the hazard or reduce its risk to an “acceptable level”. Hazard analysis is a formal/specific type of Operational Risk Management (ORM) that is required for hazardous operations. The hazard control pattern represents the relationships of the parts during the hazard analysis process. Similarly to creational pattern form in software design, the “factory” in this pattern are the sources of information, resources, or guidance and the “products” are the destinations where the action is performed or the result of the guidance provided from the factory. For instance, the test organization as a “factory” “creates”, as products, the safety personnel.

Intent: The goal behind the safety pattern is to provide a quicker solution during the development of safety control plan for T&E operations. This pattern ensures that safety control is effectively implemented in T&E operations to avoid hazard mishaps.

Also Known As: n/a

Motivation (Forces): This pattern can be used during the review and approval of an SOP for a conducting T&E of a new project. The participants involved including the test organization, SOP, walkthrough, and pilot test would collaborate to ensure that the SOP is completed and ready for use during the operation.

Applicability: This pattern is applicable during the planning and execution phases the T&E operation. For instance, during the planning phase, the SOP is developed and during execution the safety personnel complete the hazard brief requirements prior to execution.

Structure: Figure 16 depicts the hazard control structure. The structure shows the participants and their relationships with each other.

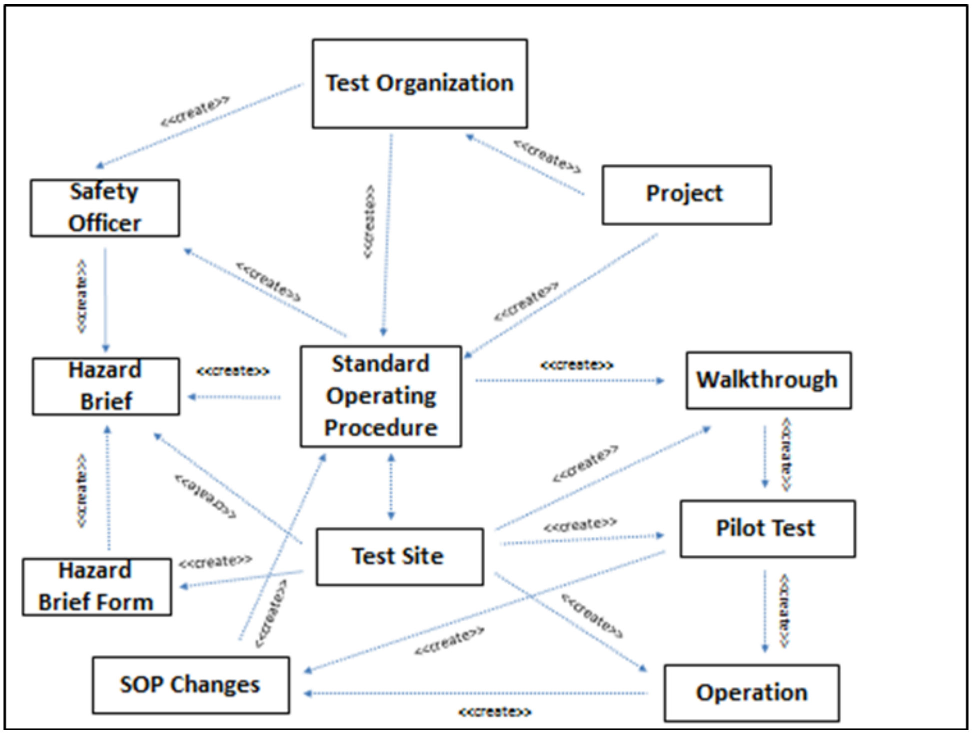

Figure 16. Hazard Control

Participants: All the participants of this pattern are shown on the structure. The test organization is the main participant.

Collaboration: Collaboration is reflected in the relationship among the participants. For instance, the safety personnel provide hazard brief forms to test team to sign after completing the hazards briefing.

Consequences: This pattern provides an easier and effective way of ensuring that hazards are controlled during operations. There are no known side effects or tradeoffs known for using this pattern.

Implementation: Some of the T&E challenges identified including safety hazards, schedule, and government policies are greatly alleviated by using this pattern.

Known Uses: Used during the approval of new SOPs and execution of T&E operations.

Related Patterns: Risk management is a related pattern hazard control pattern. In risk management, safety hazards are identified as some of the risks in a project that could result in increased cost and schedule slip if they are not effectively managed and controlled.

Structural Pattern

Name: Test Team

Test Team is a kind of structure pattern consisting of the personnel required to support a certain test. The review of past projects have provided the insight to general structure of a test team pattern that organizations tend to use when assigning personnel to different roles of a project. The test team structure represents the key stakeholders of a test organization to ensure successful completion of project requirements.

Intent: The purpose of this pattern is to ensure that the appropriate personnel are available to support all the tasks required to accomplish the project objectives.

Also Known As: n/a.

Motivation (Forces)**:** The motivation forces include personnel experience level, personnel availability, personnel skills, test requirements, and collaboration of personnel during the period of performance.

Applicability: This pattern is applied all the time during the assignment of new projects to personnel.

Structure: The structure in Figure 17 represents the Test Team pattern. It shows the test team hierarchy beginning with the test division's manager.

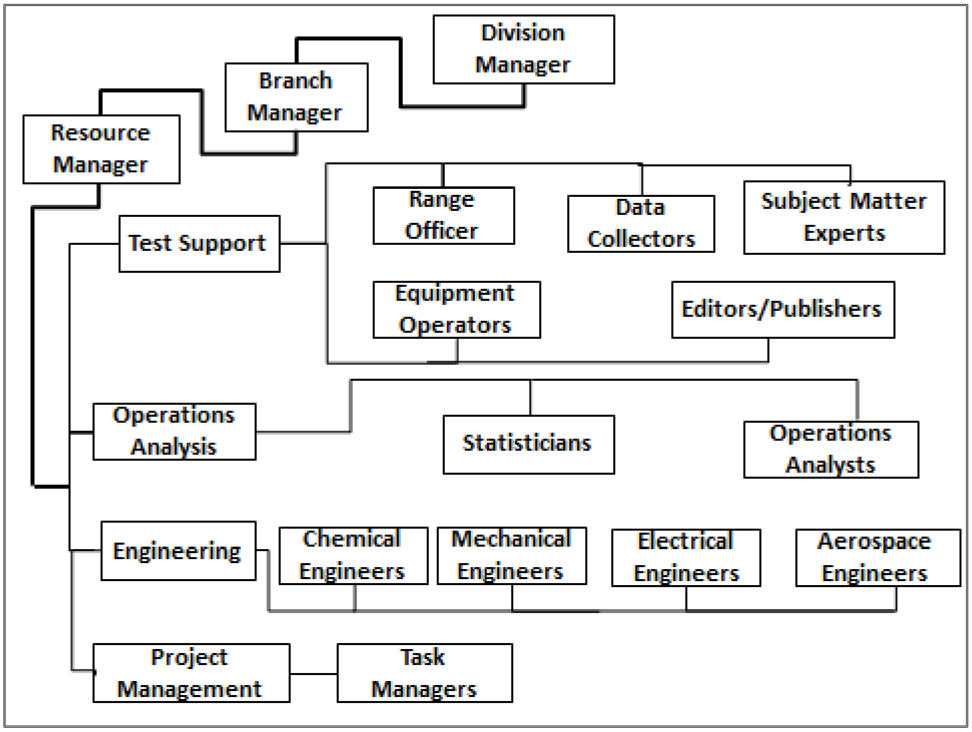

Figure 17. Test Team

Participants: participants of this pattern are all the test team personnel shown at different levels of the structure.

Collaboration: All the four levels in this pattern collaborate to achieve project's objectives. The relationship among the levels forces the participants in each level to collaborate.

Consequences: Failure to use the pattern could result to poor management of personnel or personnel skills during project execution. For instance, unskilled personnel could be assigned to wrong tasks if the pattern is not used to identify the personnel with the appropriate skills.

Implementation: This pattern is implemented during the planning of a new project. The test team is assembled following the pattern that will be used to completed project tasks.

Known Uses: Used by organizations when forming test teams for assigned projects.

Related Patterns: n/a.

Summary

Three categories of patterns were identified and described during this investigation. The three categories are behavioral, creational, and structural. The four patterns in behavioral category are primary, objective, cost estimate, and schedule. Risk management is in creational category, and the test team is in structural category. The patterns were identified using observational methodology that included reviewing the documentation of past and current projects familiar to the author. The eight patterns which are precisely described would benefit the T&E communities if implemented in their processes. Table 5 shows the pattern and corresponding challenges anticipated to be resolved if patterns are appropriately implemented.

Table 5. Patterns and Challenges in T&E Operations

Pattern Name	Challenges
Primary	Program Management
Objective	Data Collection, Cost, Schedule
Cost Estimate	Cost, Workforce, Test Equipment, Test Facilities
Schedule	Cost, Schedule, Test Equipment,
Risk Management	Cost, Hazards, Schedule, Workforce, Test Equipment, DOD Policies, Weather, Data Collection, Collaboration, Test Facilities, Program Management
Work Acceptance Process	Cost, Schedule, Test Equipment, Workforce, Test Facilities
Hazard Control	Cost, Hazards, Schedule, Workforce, Test Equipment, DOD Policies
Test Team	Workforce, Schedule, Program Management

Investigative Questions Answered

The three investigative questions answered by this research were (1) How to identify some of the challenges encountered by a typical T&E organization? (2) How to determine some of the T&E patterns organizations can use to plan, execute, and report before, during, and after T&E event? and (3) How could the T&E communities use the patterns to overcome challenges encountered during T&E operations? The first question was answered by identifying the T&E challenges through experience gained from working in a T&E organization and review of documentation of past reports. A methodology was developed that was used to develop the patterns a T&E organization would use to plan, execute, and report before, during, and after T&E event. The patterns were clearly identified and described in the simplest way possible by including only the necessary steps. The third question is about the implementation and use of the patterns to resolve T&E challenges. The implementation and known uses for each pattern are provided in pattern descriptions.

V. CONCLUSIONS AND RECOMMENDATIONS

Chapter Overview

This is the final chapter of the research and it presents the conclusion of research, significance of research, recommendations for actions and recommendations for future research.

Conclusions of Research

Eight patterns observed in the T&E community were identified and described in this research. The patterns were presented and described using the forms frequently used in the software community. Through literature review, it was determined that patterns are mostly developed and utilized in software design than in hardware or process design. The main purpose for each of the patterns identified in this research is to achieve T&E objectives in the most effective and efficient way possible. Consequently, the patterns developed here have a lot of similarity and dependence to each other. Finally, this thesis provides the answers to the three research questions investigated.

An informal survey was presented to co-workers of varying skill and experience levels for their feedback on use of patterns and response to challenges they face in their projects. The survey was designed with a Yes/No response options. The personnel were requested to review the pattern structures and T&E challenges before responding to the questionnaire. The five statements below indicate responses to the use of patterns and impact of challenges faced in T&E community. On average, the personnel agreed that:

1. The challenges identified really exist in the T&E community

2. The patterns present the processes they use
3. Reducing the occurrence and impact of T&E challenges would be more likely by using patterns.
4. They would use the patterns to resolve the identified T&E challenges
5. The difficulty of their T&E tasks is greatly alleviated by using the patterns

Significance of Research

This research identified and described patterns used in the T&E communities. These patterns are used during the execution of T&E objectives. If appropriately implemented, these patterns would help alleviate some of the commonly encountered challenges in the T&E environment such as poor project management, schedule conflicts, cost overruns, strict DoD policies, lack of appropriate test equipment and facilities, and collection of wrong data. Failure to control or eliminate the T&E challenges could result in serious impact to cost, schedule, and quality of the deliverables.

Recommendations for Action

It is recommended that all the DoD T&E communities develop and use patterns for T&E processes. The DOD T&E communities are encouraged to tailor the patterns developed as necessary to fit their T&E requirements.

Recommendations for Future Research

Compared to software engineering, there has not been much research in systems engineering processes and hardware patterns. In addition to patterns identified, there are more that can be identified and described in T&E processes. Future research is recommended to identify more T&E patterns.

Summary

This research provided an opportunity to identify and describe patterns in the T&E operations. Eight patterns including primary, objective, cost estimate, schedule, risk management, work acceptance process, and hazard control, and test team were identified. Additionally, challenges commonly experienced during the planning, execution, and reporting of T&E operations were also identified. These challenges include Cost, Hazards, Schedule, Workforce, Test Equipment, DOD Policies, Weather, Data Collection, Collaboration, Test Facilities, and Program Management. Finally, each pattern was associated with the challenges that would be resolved by implementation of the pattern.

Appendix A: Acronyms

AFIT	Air Force Institute of Technology
CE	Cost Estimate
DAU	Defense Acquisition University
DOD	Department of Defense
DT&E	Developmental Testing and Evaluation
JCIDS	Joint Capabilities Integration Development System
LFT&E	Life-Fire Testing and Evaluation
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Suitability
n/a	Not Applicable
OpPlan	Operations Plan
OT&E	Operational Testing and Evaluation
PoP	Period of Performance
Ro	Operational Reliability
SECNAVINST	Secretary of the Navy Instruction
SEP	Systems Evaluation Plan
SLP	Service Life Projection
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SOW	Statement of Work
T&E	Test and Evaluation
TAD	Temporary Assignment of Duty
WAP	Work Acceptance Process
WAR	Work Acceptance Review
WUA	Work Unit Assignment

Vita

Daniel Mutunga started his engineering career in Kenya, Africa. He completed primary and high school education in Kenya before moving to United States for higher education. Daniel attended and graduated with honors from Seminole Community College, Sanford, FL before transferring to the University of Central Florida (UCF), Orlando, FL for a Bachelor of Science Degree in Electrical Engineering. After receiving the Bachelor of Science degree, Daniel joined Naval Surface Warfare Center Crane, Detachment Fallbrook, CA as an electrical engineer supporting Test and Evaluation projects. He joined the Navy's Systems Planning, RD&E (SPRDE)-Systems Engineering workforce through the Naval Acquisition Intern Program (NAIP). During the program duration, Daniel completed all the NAIP's requirements including Defense Acquisition Workforce Improvement Act (DAWIA) SPRDE Level 3 DAWIA Certification. During the NAIP program, Daniel started his Master of Science degree in Systems Engineering – Test and Evaluation at Air Force Institute of Technology (AFIT), Wright Patterson Air Force Base (WPAFB), OH. Daniel completed his course work in Fall 2012 and completed the thesis research in January, graduating with a MS. Degree in March 2013.

Daniel is currently working as an Electrical/Systems Engineer at Naval Surface Warfare Center Crane, Detachment Fallbrook, CA supporting the Test and Evaluation of Marine Corps and Army landing force Systems and ammunition. As a Project Leader in the Test and Evaluation environment, he is mainly responsible for planning, execution, and reporting on projects. The future goals are to obtain a Doctorate Degree and continue supporting the Department of Defense in Test and Evaluation efforts.

Bibliography

Defense Acquisition Guide. (2012, January 10).

Ambler, S. W. (1998). *An Introduction to Process Patterns.* Cambridge University Press.

Claxton, J. D. (2005). *Test and Evaluation Management Guide.* Fort Belvoir : The Defense Acquisition University Press.

Cloutier, D. R. (2012). *Patterns & Systems Engineering*. Retrieved 11 9, 2012, from Patterns & Systems Engineering: http://sepatterns.typepad.com/sepatterns/

Cloutier, R. (2009). *Center for Patterns & Systems Engineering*. Retrieved 10 21, 2012, from Center for Patterns & Systems Engineering/about.htm: http://www.patterns4se.com/about.htm

CRANE, N. (2009). *Hazard Analysis For Hazardous Operations and Operational Risk Management.* Crane: NSWC Crane.

Creswell, J. W. (2002). Research Design. In J. W. Creswell, *Research Design* (p. 246). Lincoln: Sage Publications.

Data & Object Factory, LLC. (2001-2013). *dofactory*. Retrieved January 29, 2013, from www.dofactory.com: http://www.dofactory.com/Patterns/Patterns.aspx

Defense Acquisition University. (2005, January). Test and Evaluation Management Guide. Fort Belvoir, VA, USA.

Department of Defense (1996, 4l 3). Department Of Defense Handbook for Preparation of Statement Of Work (SOW)-MIL-HDBK-245D. Arlington, VA, USA. Retrieved from https://www.acquisition.gov/SevenSteps/library/DODhandbook.pdf:

Department of Defense. (2006). *Risk Management Guide for DoD Acquisition.*

Denis. (2010, 11). *Planning and Risk*. Retrieved 12 2012, from Expert Program Management: http://www.expertprogrammanagement.com/2010/11/planning-and-risk/

Department of the Navy Office of the Secretary. (2011, 9 1). SECNAV Instruction 5000.2E. District of Colombia, Washington, USA: Department of the Navy.

Dong, J., Zhao, Y., & Sun, Y. (2009, November). *A Matrix-Based Approach to Recovering Design Patterns.* IEEE Transactions On Systems, Man, And Cybernetics.

Dougherty, Sayre, Seacord, Svoboda, & Togashi. (2009). *Secure Design Patterns.* Carnegie Mellon University.

Erl, T. (2009). *SOA Design Patterns.* Boston: Prentice Hall.

Fabrycky, B. S. (2006). *Systems Engineering and Analysis, Fourth Edition.* Upper Saddle River: Pearson Prentice Hall.

Fowler, M. (2005, February 19). *Patterns in Enterprise Software*. Retrieved January 30, 2013, from Patterns in Enterprise Software: http://martinfowler.com/articles/enterprisePatterns.html

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). *Design Patterns.* Upper Saddle River: Addison-Wesley.

Gilmore, J. M. (2010, 4 23). Memorandum For Commander, U.S. Army Test And Evaluation Command Commander, Operational Test And Evaluation Force Commander, Air Force Operational Test And Evaluation Center Director, Marine Corps Operational Test And Evaluation Activity Commander, Joint I. DC, Washington, USA.

Gilmore, J. M. (2012). *FY 2012 Annual Report.*

Heldman, K. (2012). *Project Manager's Spotlight on Risk Management.* San Francisco: Jossey-Bass.

Hulett, D. H. (2004). *Assessing Risk Probability : Alternative Approaches.* Prague, Czech Republic: 2004 PMI Global Congress Proceedings.

Larman, C. (2004). *Applying UML and Patterns: An introduction ot Object-Oriented Analysis and Design and Iterative Development.* Upper Saddle River: John Wait.

Office of Security Review Department of Defense 12-S-0150. (2011, 10 24). Incorporating Test and Evaluation into Department of Defense Acquisition Contracts. Washington, DC, USA.

Project Management Institute. (2008). *A Guide to the Project Management Body of knowledge (PMBOK GUIDE) Fourth Edition.* Pennsylvania: Project Management Institute, Inc.

Simon, D. H. (2012). *Practical Project Risk Management: The ATOM Methodology*. Tysons corner: Management Concept Press.

USD(AT&L). (2007, 11 20). DoD Directive 5000.1.

USD(AT&L). (2008, 12 8). DoDI 5000.02: Operation of the Defense Acquisition System. *Department of Defense Instruction*. USD(AT&L).

Wikipedia. (2012). *Software design pattern*. Retrieved 10 2, 2012, from wikipedia: http://en.wikipedia.org/wiki/Software_design_pattern

Wolfe, B., & Hohpe, G. (2004). *Enterprise Integration Patterns.* Boston: Pearson Education, Inc.

Zulkernine, A. K. (2012). *A Comparative Study of Software Security Pattern Classifications.* 2012 Seventh International Conference on Availability, Reliability and Security.

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14. ABSTRACT

This research focuses on identification and description of patterns used in Test and Evaluation (T&E) operations. Patterns are defined as named and well-known problem/solution pairs that can be applied in new contexts, with advice on how to apply it in a novel situations and discussion of its trade-offs, implementations, and variations. They have a well established and used in software engineering, but have only recently been considered for systems engineering. In the Department of Defense (DOD), T&E is required for all acquisitions prior to transitioning into operations. As identified and described in this thesis, each of the patterns fits in one of the three categories: behavioral, creational, and functional. The research has identified eight named patterns to include: primary pattern, objective pattern, cost estimating pattern, scheduling pattern, risk management pattern, work acceptance process pattern, hazard control pattern, and test team pattern. The implementation of patterns by Department of Defense is expected to alleviate some of the common challenges encountered during T&E, provide a consistent higher quality and expectation, as well as efficiently use test infrastructure and personnel resources.

15. SUBJECT TERMS

Patterns, T&E, Schedule, Planning, Execution

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